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Redshift-Distance Survey of Early-type Galaxies. I. Sample Selection, Properties and Completeness [1]

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ABSTRACT

This is the first in a series of papers describing the recently completed all-sky redshift-distance survey of nearby early-type galaxies (ENEAR) carried out for peculiar velocity analysis. The sample is divided into two parts and consists of 1607 elliptical and lenticular galaxies with $cz \leq 7000$ kms^{-1} and with blue magnitudes brighter than $m_B = 14.5$ (ENEARm), and of galaxies in clusters (ENEARc). Galaxy distances based on the $D_n - \sigma$ and Fundamental Plane (FP) relations are now available for 1359 and 1107 ENEARm galaxies, respectively, with roughly 80% based on new data gathered by our group. The $D_n - \sigma$ and FP template distance relations are derived by combining 569 and 431 galaxies in 28 clusters, respectively, of which about 60% are based on our new measurements.

To date the ENEAR survey has accumulated: 2200 $R-$band images yielding photometric parameters for 1398 galaxies; and 2300 spectra yielding 1745 measurements of central velocity dispersions and spectral line indices for 1210 galaxies. In addition, there are some 1834 spectra of early-type galaxies available in the SSRS+SSRS2 database out of which roughly 800 galaxies yield high-quality measurements of velocity dispersions and spectral line indices, bringing the total number of galaxies with available spectral information to about 2000. Combined with measurements publicly available, a catalog has been assembled comprising: $\sim$ 4500 measurements of central velocity dispersions for about 2800 galaxies; $\sim$ 3700 measurements of photometric parameters for about 2000 galaxies; distances for about 1900 galaxies. This extensive database provides information on galaxies with multiple observations from different telescope/instrument configurations and from different authors. These overlapping data are used to derive relations to transform all available measurements into a common system, thereby ensuring the homogeneity of the database.

The ENEARm redshift-distance survey extends the earlier work of the 7S and the recent Tully-Fisher surveys sampling a comparable volume. In subsequent papers of this series we intend to use the ENEAR sample by itself or in combination with the SFI Tully-Fisher survey to analyze the properties of the local peculiar velocity field and to test how sensitive the results are to different sampling and to the distance indicators. We also anticipate that the homogeneous database assembled will be used for a variety of other applications and serve as a benchmark for similar studies at high-redshift.

Subject headings: cosmology: observations – cosmology: large-scale structure of universe – galaxies: distances and redshifts – galaxies: elliptical and lenticular, cD – galaxies: fundamental parameters

1. Introduction

Measurements of the peculiar motions of galaxies in the nearby universe represent one of the most powerful tools available to probe mass fluctuations on scales $\lesssim 100 \mathrm{h}^{-1}$ Mpc, complementing current efforts to measure the amplitude of these fluctuations from one-degree scale observations of the cosmic microwave background and on very large scales as obtained from the analysis of COBE data (e.g., Górski et al. 1996). Analysis of the peculiar velocity field provides not only a direct test of the gravitational instability picture but it also enables the relationship between galaxies and the underlying mass distribution to be investigated. Moreover, to the extent that this relationship can be adequately modeled, for instance by a linear biasing model, comparison between peculiar velocity and redshift data can be used to determine the parameter $\beta = \Omega^{0.6}/b$, where Ω and b are the density and linear biasing parameters, respectively (e.g., Dekel 1994; Strauss & Willick 1995).

While the importance of cosmic flows to cosmological studies has long been recognized, and a variety of methods for analyzing peculiar velocity data have been developed over the years, the progress of redshift-distance surveys suitable for such studies has been relatively slow. Most of the work in the field relied until recently in the Tully-Fisher (TF) and $D_n - \sigma$ samples of Aaronson et al. (1982) and Lynden-Bell et al. (1988, hereafter 7S), respectively, complemented by relatively small samples covering particular regions of the sky (Willick 1991; Courteau et al. 1993). Early analyses led to important results such as the discovery of the Great Attractor by the 7S and to the rejection of the high-bias CDM model as a viable cosmological model. However, the sparseness of the samples and the relatively small effective volume they probe also led to results and interpretations that need further confirmation. These include large derived values of the cosmological density parameter, at variance with other estimates, and the existence of large scale coherent motions, suggestive of excess power at very large scales (Willick 1990; Mathewson, Ford & Buchhorn 1992, hereafter MFB; Courteau et al. 1993).

Recently, the observational situation has significantly improved with the completion of large TF surveys in both hemispheres (MFB; Mathewson & Ford 1996; Giovanelli et al. 1997 a,b; Haynes et al. 1999 a,b). Combined, they provide the largest all-sky sample currently available for peculiar velocity studies greatly extending the depth and the number of galaxies of earlier surveys. There still are, however, points of concern.

First, these surveys were carried out independently with different selection criteria, different observing and reduction techniques and have been assembled in different ways to produce all-sky catalogs suitable for

analysis such as the SFI (e.g., da Costa et al. 1996; Giovanelli et al. 1998) and Mark III (Willick et al. 1997) catalogs. These catalogs differ both in the data sets used to assemble them and in the transformations employed to map the MFB data in the Southern hemisphere onto a common system. Analysis of these catalogs have led to both consistent (e.g., Zaroubi et al. 1996; Freudling et al. 1999) and conflicting results (e.g., Nusser, Davis & Willick 1997; da Costa et al. 1998a; Borgani et al. 1999; Willick & Strauss 1998) depending on the type of analysis considered.

Second, most redshift-distance surveys of the whole sky currently available, including the recently completed Shellflow survey (Courteau et al. 1999), rely primarily on TF distances. While other recent investigations that have used early-type galaxies, have either focused on motions of clusters of galaxies (e.g., EFAR, Wegner et al. 1996, Colless et al. 1999; SMAC, Hudson et al. 1999; LP10K, Willick 1999) or have concentrated on pre-chosen areas of the sky which do not render them optimal for all types of analyses (e.g., Müller et al. 1998; Müller, Wegner & Freudling 1999). Finally, recent attempts to use more accurate distance indicators, such as the SBF method (Tonry, Blakeslee, & Dressler 1999) and SNeIa (e.g., Riess 1999), remain limited in depth and in the number of objects with measured distances to be used for a detailed mapping of the peculiar velocity field (but see Blakeslee et al. 1999).

In order to address some of these concerns we have carried out the so-called ENEAR survey, an extensive spectroscopic and $R-$band imaging survey of a sample of nearby early-type galaxies (thus the choice of the name to contrast with the EFAR project) brighter than $m_B = 14.5$ and $cz \leq 7000 \mathrm{kms}^{-1}$ (hereafter ENEARm), extracted from complete redshift surveys, and of galaxies in 28 selected clusters (ENEARc). Currently, the ENEARm and ENEARc samples comprise 1359 and 569 galaxies with measured distances, respectively. More importantly, 82% of the ENEARm galaxies and 58% of the ENEARc galaxies have distance estimates based on new measurements obtained by our group in both hemispheres, making it the largest homogeneous all-sky survey of its kind conducted by a single group. The primary goal of this survey has been to extend the 7S sample to fainter magnitudes, thereby probing a volume comparable to that of existing TF surveys such as the SFI. With such a sample it is possible to: 1) investigate the reproducibility of the results obtained from the analysis of peculiar velocity data as measured by different secondary distance indicators; 2) combine it with the TF surveys to produce a homogeneous all-sky catalog of galaxies of different morphological types, sampling both low and high density regions; and 3) provide a denser sampling of the gravitational field.

The ENEAR survey began as an outgrowth of spectroscopic surveys carried out in the Southern

hemisphere started in 1982 (e.g., SSRS+SSRS2, da Costa et al. 1988, 1998b). Although these surveys were primarily designed for redshift measurements, from the start an attempt was made to obtain higher signal-to-noise spectra for bright early-type galaxies for their eventual use in the measurement of central velocity dispersions and spectral line indices. The original goal was to provide spectral information for a magnitude-limited sample which could be used as a basis for the statistical analysis of the properties of this population as a function of the local galaxy density and different types of environment. By 1988, motivated by the results of the 7S analysis and the start of the SFI TF-survey attention shifted to the peculiar velocity field and R-band imaging was initiated for a sample selected from a combination of magnitude-limited samples with complete redshift information available at the time. This sample was later extended to lower galactic latitudes as described below. In the meantime, several galaxies with only older spectra were re-observed to ensure the quality and uniformity of the sample. In 1993 the campaign to observe northern galaxies began mostly at the MDM Observatory.

As a result we have accumulated a large number of spectra and images from which we have measured redshifts, central velocity dispersions, spectral line indices and several photometric parameters. We have assembled this information together with spectroscopic and photometric parameters available in the literature, to produce a homogeneous catalog of early-type galaxies, hereafter ENEAR catalog. New data continue to be recorded in the catalog as the observations of early-type galaxies are still in progress. We hope to make our database accessible on-line in the future.

The large number of galaxies in the ENEAR catalog, most of which with new high-quality spectra and CCD images, its homogeneity and the improved membership assignment of galaxies to groups/clusters for a significant fraction of the galaxies make this catalog a valuable tool for many other applications. The ENEAR catalog, currently the largest uniform database of its kind, is ideally suited for: the statistical characterization of the properties of present-day early-type galaxies; stellar populations studies using different spectral line indices; testing the universality of distance relations such as the $D_n - \sigma$ and the Fundamental Plane (FP); assessing the influence of different types of environment and the dependence of the properties of these galaxies on the local density of galaxies; and constraining models for the formation and evolution of ellipticals (e.g., Bernardi et al. 1998). We also anticipate that the present sample will be used as a benchmark to comparable high-redshift studies.

The ENEAR survey represents a significant improvement over previous redshift-distance surveys of early-type galaxies. Besides the larger number of galaxies, about a factor of three larger than the 7S

sample, most of the galaxies have new measurements of velocity dispersion, in general obtained from higher resolution spectra, and photometric parameters derived from the analysis of R-band images. To ensure uniformity, a large number of observations have been obtained of galaxies with measurements available from other authors or from different telescope/instrument configurations enabling all available measurements to be scaled to a uniform system. Since the survey has been conducted by a single group, all of the data were analyzed using the same procedure, further ensuring their uniformity, and the observations were coordinated so as to reach the same level of completeness over the whole sky. Finally, the homogeneous and well-defined sample suitable for peculiar velocity analysis is a subset of magnitude-limited samples for which complete redshift information is available from surveys such as CfA1+CfA2 (Huchra et al. 1983; Geller & Huchra 1989; Falco et al. 1999), SSRS+SSRS2 and ORS (Santiago et al. 1995), thus allowing an objective assignment of galaxies to groups/clusters.

This paper is the first in a series reporting the results of the ENEAR survey. Its primary goal is to give an overview of the project and provide the basic information which will be used in future papers of this series. In Section 2, we provide details of the procedure adopted in the selection of a well-defined sample for peculiar velocity analysis and of its general characteristics. We also discuss the selection of the cluster sample, which will be used in subsequent papers to construct template distance relations. In Section 3, we briefly describe our new spectroscopic and R-band imaging data. We also discuss the procedure adopted for the homogenization of the data either newly obtained with different telescopes/instrument configurations or available in the literature. Such a procedure is of paramount importance in the elimination of inconsistencies between data from different sources in order to minimize systematics. In addition, we summarize the data currently available in the ENEAR catalog that has been assembled in the course of this project. In Section 4, we briefly discuss the method employed to estimate galaxy distances, the procedure adopted for pruning the sample of galaxies unsuitable for peculiar velocity studies and describe the criteria employed for assigning galaxies to groups/clusters. This grouping is crucial for reducing the influence of virial motions and decreasing distance-errors. We also discuss the completeness of our redshift-distance survey, compare our sample with those of previous peculiar velocity studies and give a preview of the measured peculiar velocity field. Finally, a brief summary is presented in Section 5.

2. Sample Selection

2.1. ENEARm: The magnitude-limited sample

As pointed out above the primary goal of the ENEAR project has been to extend the volume probed by the 7S sample, which considered early-type galaxies brighter than $m_B \sim 13.5$ sampling the peculiar velocity field within an effective volume ~ 4000 kms^{-1} in radius. An equally important results is that this complements the SFI TF redshift-distance survey of late spirals (e.g., Haynes et al. 1999a,b) out to $\lesssim$ 7000 kms^{-1} .

To achieve our goal we assembled all the available complete redshift surveys at the beginning of this project (in 1988) to construct an all-sky sample. Originally the following samples were used: 1) the CfA1 sample (Huchra et al. 1983), covering the regions $b > 40°$ and $\delta > 0°$ in the northern galactic cap, and $b < -30°$ and $\delta > -2.5°$ in the southern hemisphere; 2) the sample of galaxies used in the SSRS (da Costa et al. 1988) covering the regions $b < -30°$ and $\delta \leq -17.5°$ in the southern galactic cap, and $b > 40°$ and $\delta < -17.5°$ in the northern galactic cap; 3) the equatorial survey sample of Huchra et al. (1993) filling in the gaps between the first two samples near the equator. The samples for these redshift surveys were extracted from different catalogs which include: The Surface Photometry Catalogue of the ESO-Uppsala Galaxies (ESO, Lauberts & Valentjin 1989), the Morphological Catalog of Galaxies (MCG, Vorontsov-Velyaminov & Arhipova 196), the Uppsala General Catalog (UGC, Nilson 1973) and the Catalog of Galaxies and Clusters of Galaxies (CGCG, Zwicky et al. 1961-1968). Magnitudes for the SSRS galaxies were assigned based on magnitude-diameter relations derived by Pellegrini et al. (1990) who made the first attempt to construct a uniform magnitude-limited sample for the whole sky, with additional checks on the relative differences in the magnitudes of the different catalogs being conducted later (Alonso et al. 1993, 1994). In the southern hemisphere the ENEAR magnitudes have been compared to the more recent SSRS2 magnitude system (da Costa et al. 1998b). We find that the magnitudes obtained from the magnitude-diameter relation show a linear relation with a scatter of ~ 0.45 mag. More recently, galaxies drawn from the ORS (Santiago et al. 1995) were added in order to extend the sample towards lower galactic latitudes and cover at least part of the Great Attractor region.

Magnitudes used in the different catalogs were converted into an approximately homogeneous system using statistical corrections between the various systems as described in Pellegrini et al. (1990) and da Costa et al. (1998b). However, as discussed in these papers the individual magnitudes can have errors as large as 0.5 mag. The morphological types adopted in our final catalog are those from Lauberts & Valentijn (1989), and the types given in the other catalogs have been converted into this system. From the

experience accumulated in the morphological classification of the SSRS2 (da Costa et al. 1998b) we know that morphological misclassifications are frequent and in the course of the observations several objects had to be removed both before, based on the examination of the digitized sky survey (DSS, Lasker et al. 1990), and after the observations from the examination of the gathered CCD images, as discussed below.

From the all-sky sample we have drawn 1847 galaxies brighter than $m_b = 14.5$, with morphological types $T \leq -2$ and $cz \leq 7000$ kms^{-1} . These criteria define the original ENEARm sample considered for peculiar velocity studies, but as shown below it includes a significant number of galaxies which, for different reasons, are not suitable for observations or for estimating distances. The sample comprises 471 galaxies with $T \leq -5$, 305 galaxies with $T = -3$, and 1071 with $T = -2$, but these numbers should be viewed only as a rough indication of the morphological mix of the catalog, given the uncertainties in the classification. The redshift distribution of the sample is shown in Figure 1, where it is compared to that expected for a $m_B = 14.5$ magnitude-limited sample and to the redshift distribution of galaxies in the 7S sample. The predicted distribution was obtained using the luminosity function parameters derived by Marzke et al. (1998) for early-type galaxies, normalized to the area of the sky covered by the ENEARm sample. The redshift cutoff was adopted to ensure that the sample depth was comparable to that of the SFI, and as a trade-off between reaching a high level of completeness in the nearby volume and the available observing time. The ENEARm sub-sample corresponds to $\sim 85\%$ of the total number of early-types in a $m_B = 14.5$ magnitude-limited sample.

The projected distribution of the ENEARm sample is shown in Figure 2. Comparison of this figure with that shown, for instance, in Santiago et al. (1995) for an all-sky sample to about the same depth shows that the ENEARm densely probes the most prominent large-scale structures in the nearby universe including Virgo, the Great Attractor region and its extension to the Telescopium-Pavo-Indus supercluster, and the Perseus-Pisces complex. Also note the presence of areas devoid of galaxies which correspond to high-extinction regions as shown by Santiago et al. (1995).

2.2. ENEARc: The Cluster Sample

The ENEARm sample is complemented by a cluster sample, hereafter ENEARc, which has been used to define template distance relations (Bernardi et al. 1999b) combining all available cluster data. The sample consists of groups identified in ENEARm (see section 4.3) with more than 10 members and at least 5 early-type galaxies to which we have added clusters selected from the literature. The latter were not

identified as groups because either most of the member galaxies are fainter than the ENEARm limiting magnitude, have redshifts beyond its redshift limit, or are outside the surveyed region at low galactic latitudes. In addition, to the clusters identified as groups, fainter members have been added according to a membership criteria similar to that described below (see section 4.3) and discussed in more detail by Bernardi et al. (1999a). A total of 37 groups were identified satisfying our cluster definition, nearly all associated with Abell/ACO clusters. The ENEARc sample currently comprises a total of 28 clusters, 22 of these identified in the volume probed by ENEARm. For most of these clusters a large number of modern observations are available in the literature. This provides an adequate sample to derive distance relations. Instead of observing new systems preference was given to the observation of as many galaxies as possible already with available data from different sources, primarily from Jørgensen et al. (1992, 1995 a,b) and 7S. This was done to enable us: to bring all of the available data, both in clusters and in the field, to a common system; to substitute old measurements of central velocity dispersions and of photometric parameters, whenever required; to obtain better resolution and higher S/N spectra for galaxies in clusters for comparison with similar data for galaxies in low density regions; to enlarge the sample of galaxies with the parameters required for the derivation of the FP; to enlarge the sample of galaxies in clusters with measured distances to improve the statistics of the template relation.

Figure 3 shows the redshift distribution of the 28 clusters presented in Bernardi et al. (1999a) which span a range of redshifts up to $cz \sim 10,000$ kms^{-1} with an approximately uniform number per redshift bin. Also shown is the redshift distribution of all the cluster members identified using the membership assignment described below. The spatial distribution of these clusters is shown in Figure 4 where three orthogonal projections in Supergalactic cartesian coordinates are displayed.

3. Data

As already stated, the primary objective of the present redshift-distance survey has been to produce an all-sky homogeneous sample for peculiar velocity analysis. With a few exceptions, most recent work in the field has had to rely on the combination of samples from diverse sources, using different selection criteria, observing strategies and reduction procedures. This has made the homogenization of the measurements from different sources very difficult and their errors poorly understood. By contrast, even though measurements from different authors are used in compiling our final homogeneous redshift-distance catalog, about 77% and 65% of early-type galaxies with available photometric and spectroscopic data, respectively, are from

new observations obtained as part of this project over the whole sky. This together with the large number of galaxies with multiple observations from different telescope/instrument configurations and in common with other authors enables the internal and external homogenization of the whole data set, the measurement of parameters with an improved accuracy and the possibility of cross-checks between different data sets.

While the imaging observations described here are limited to the ENEAR samples (ENEARm+ENEARc) presented above, spectra have been obtained for galaxies belonging to the ENEARm and ENEARc samples as well as for other early-type galaxies observed as part of several spectroscopic surveys conducted in the Southern hemisphere (e.g., SSRS, SSRS2). Measurements of the central velocity dispersion and of spectral line indices for galaxies with spectra deemed suitable for these calculations have also been included in our ENEAR catalog presented below to further enlarge the database of spectroscopic parameters characterizing present-day early-type galaxies for studies other than peculiar velocity analysis. In later papers in this series we will present these additional measurements together with those obtained from the ENEAR survey proper (Wegner et al. 2000; Rité et al. 2000).

3.1. ENEAR: Spectroscopic Observations

Our spectroscopic observations have been carried out over a long period of time using a variety of telescopes and instruments (CASLEO, CTIO, ESO, LNA and MDM), detectors and gratings, with the spectral resolution ranging from 2 to 5 Å. Some of the data originating as far back as the mid-80s were obtained using the intensified photon-counting Reticon detector utilized in the Southern Sky Redshift Survey (SSRS, da Costa et al. 1991). The observing and data reduction procedures are similar to those used in the EFAR survey (Wegner et al. 1999).

To date a total of $\sim$ 2000 spectra of early-type galaxies taken from the ENEARm and ENEARc sample have been obtained. However, some of these spectra have not yielded reliable measurements of the spectroscopic parameters of interest (velocity dispersion; spectral lines indices). These cases include strong emission-line galaxies with weak absorption features, low surface brightness galaxies yielding low S/N spectra and galaxies too close to bright stars. Others, especially the older Reticon data, lead to measurements with large errors compared to our most recent observations and most have been or are in the process of being re-observed.

Of the total number of available spectra, 1745 were suitable to measure the central velocity dispersion

of 1210 galaxies, including 535 multiple spectra of 327 galaxies. The number of repeated observations range from two to more than 10 for a few comparison galaxies. The multiple observations were used to compare spectra obtained with different telescope/instrument configurations and have been used to make our measurements internally consistent. They have also been used to calibrate our internal error estimates (Wegner et al. 2000). In addition, we have observed about 200 galaxies with measurements available in the literature to derive statistical corrections and bring those data into a uniform system (Bernardi et al. 1999a).

By analyzing these spectra we have measured redshifts, velocity dispersions and Mg_2 line indices (Wegner et al. 2000) and Figure 5 shows the distribution of these quantities for all ENEAR spectra deemed suitable for these measurements. Also shown are the same distributions as measured from spectra obtained using a resolution of $\lesssim$2.5 Å. Over 80% of the spectra were obtained at high-resolution allowing us to make more accurate measurements, especially for galaxies with $\sigma \lesssim$100 kms^{-1}. The distribution of the differences between our redshifts and those available in the literature is shown in Figure 6. In general the agreement is excellent leading to an rms of the differences $\sim$30 kms^{-1} . Note, however, the presence of a few outliers which should be taken into account when computing peculiar velocities. Since our measurements have been obtained from high S/N in computing peculiar velocities we give preferences to these new measurements. Moreover, from our data we find 86 emission-line galaxies, out of which about 60 show no evidence of being misclassified spirals. Some of these have very strong emission lines and weak absorption features which may indicate the presence of residual star-formation. A detailed description of the observations, data reduction, and derived spectroscopic parameters is given in Wegner et al. (2000). Finally, we point out that in addition to the Mg_2 line index used by Bernardi et al. (1998), several other spectral indices are being computed and will be presented in a future paper (Rité et al. 2000).

Our spectroscopic parameters have been converted onto a uniform system using the many repeated observations we have in different runs in both hemispheres. Our fiducial system is defined by our high-resolution spectra ($\sim$ 2.5 Å). In addition, we used measurements of 200 galaxies in common with other sources to derive corrections to scale the data in the public domain to our system. From these external comparisons we find that our errors are typically 8% in σ and 0.01 mag in Mg_2, consistent with our internal estimates (Wegner et al. 2000).

3.2. ENEAR: Photometric Observations

Since 1988, photometric observations in R-band have been made using different telescopes in the northern (FLWO, MDM) and southern hemispheres (CTIO, ESO). About 2200 images have been obtained of which 1896 were taken in photometric conditions. From these images we have measured photometric parameters for 1398 galaxies. Most of the data were taken with large format CCDs, allowing for good sky subtraction and, occasionally, for observing more than one galaxy per frame, especially for galaxies in groups/clusters. Some galaxies were later discarded because they were unsuitable for measurements of the photometric parameter of interest (e.g., stellar contamination; crowded fields; interacting galaxies or superposed galaxy images; misclassification).

Because the imaging observations were conducted over an extended period of time, an attempt was made to obtain repeated observations in every run to provide the necessary data for run-to-run corrections. Such observations have been used to transform all of our measurements into a common internal system.

All images were reduced using standard *IRAF* tools, and surface photometry was carried out by fitting elliptical and circular aperture to the two-dimensional light distribution of each galaxy. Light profiles were fitted either by a pure de Vaucouleurs' $r^{1/4}$ law or in combination with an exponential profile to represent the light distribution of bulge+disk systems. The fits used the algorithm which was developed in the EFAR survey (Saglia et al. 1997). This also corrects for the smearing effects due to seeing and provides information about the quality of the fit. The main photometric parameters derived are d_n, the angular diameter within which the mean surface brightness is equal to $\bar{\mu}_R = 19.25$ mag arcsec^{-2}, the half-light radius, r_e, the mean surface brightness within this radius, $\bar{\mu}_e$, as well as global quantities such as total magnitudes, m_R, the disk-to-bulge ratio, D/B, ellipticity, position angle and parameters which can be used to characterize the shape of images. Figure 7 shows the distribution of $\log d_n$, $\log r_e$, $\bar{\mu}_e$ and the disk-to-bulge ratio D/B for all observed galaxies for which these parameters could be measured. The first three parameters are used in defining the distance relations, while D/B has been used as an indicator of possible misclassifications or inadequate light profile fitting. Details of the observations, data reduction, analysis and tables listing the photometric parameters will be presented by Alonso et al. (2000 a,b).

As mentioned above our derived values of photometric parameters ($\log\ d_n$, $\log\ r_e$, $\bar{\mu}_e$) were transformed into an internally consistent system using repeated observations. In total, 498 observations of 358 galaxies are available for assessing these statistical corrections. By careful examination of all multiple observations available, internal conversion relations were derived for each photometric parameter of interest and were

used to create a uniform internal system. In addition, we observed 346 galaxies in common with other sources, including 100 galaxies in the 7S sample for which no images were previously available, to derive corrections to scale the data in the public domain to our system. From the comparison between our measurements and those of other authors we estimate that the typical errors in $\log d_n$, $\log r_e$, and $\bar{\mu}_e$ are 0.017 dex, 0.08 dex, and 0.3 mag arcsec^{-2}, respectively. These values are consistent with our internal estimates. Finally, it is also worth mentioning that some ∼150 galaxies have also been observed in the B-band and ∼200 in the J and K' near-IR bands. These data will be presented in forthcoming papers.

3.3. ENEAR: The Catalog of Early-type Galaxies

In the course of this work we have assembled all of the spectroscopic and photometric data gathered by the ENEAR survey, the spectroscopic data from other ongoing observations in the Southern hemisphere and most of the available data in the literature into a uniform catalog of early-type galaxies, which we will refer to as the ENEAR catalog. The main goal of producing this catalog was to minimize the number of galaxies that required observations, and to produce a homogeneous database for other applications. Even though extensive, the compilation from the literature is not complete as preference was given to data in the redshift range of interest. Table 5 summarizes the contribution from different sources included in the present catalog listing: in column (1) the source; in column (2) the number of galaxies with measured central velocity dispersion; in column (3) number of galaxies with measured Mg_2 line index; in column (4) the number of galaxies with measured d_n; and in column (5) number of galaxies with available FP parameters. Also included are the older compilations of central velocity dispersion measurements carried out by Tonry & Davis (1981) and Whitmore et al. (1985), even though, in general, these data are not used in combination with newer data. We also give the number of early-type galaxies measured by our group in the Southern hemisphere which are not part of the ENEAR survey, as described in this paper, but have been already analyzed by Rité (1999). We refer to this additional sample as ENEAR+.

From the literature, the bulk of the data still comes from the all-sky sample of 7S galaxies (e.g., Faber et al. 1989 and as distributed by D. Burstein in electronic form, the so-called Mark II catalog). A revised version of the spectroscopic parameters has recently been kindly provided by D. Burstein. With the exception of this sample, most other available data sets are primarily in clusters of galaxies. It is also important to emphasize that the data as a whole are very inhomogeneous. The spectroscopic parameters were derived from spectra obtained with very different spectrographs (e.g., photon-counting detectors,

using small slits; CCD detectors, using long-slits). The original spectra also have a wide range of resolutions and spectral coverage. Similarly, the photometric data include old photo-electric photometry and images using small and large format CCDs, and were obtained using different filters.

Therefore, the measured parameters cannot be used as listed in the original sources but must be first transformed into a common scale, utilizing the conversion relations derived from overlapping data as described above. In our final catalogs whenever data from other authors are used they have been corrected as described in Bernardi et al. (1999a). This procedure has been helpful in maximizing the use of publicly available data and has enabled us to reach a higher completeness of the ENEAR samples.

Currently, in our database there are $\sim$ 4500 measurements of velocity dispersion, 3700 values of the d_n parameter and 2304 values of the combination $FP = \log\ r_e$ - $0.3\bar{\mu}_e$, as used in the FP relation. These yield 2797 galaxies with measured central velocity dispersion, 1960 galaxies with d_n, 1588 galaxies with FP, 1847 and 1458 galaxies with the required information to compute their distances using the $D_n - \sigma$ and FP relations, respectively. From these data, distances to 76% of the ENEARm galaxies and 89% of the ENEARc sample can be estimated.

In our final catalog, galaxies with more than one measurement of d_n, redshift and velocity dispersion were combined, discarding measurements from compilations, using an error-weighted mean of the different measurements, eliminating outliers whenever possible.

4. Redshift-distance Catalog for Peculiar Velocity Analysis

4.1. Distance Relation

Measurement of the radial component of galaxy's peculiar velocity, $v_p = cz - R$, requires knowing its redshift cz and its redshift independent distance R (in units of kms^{-1}), which must be determined using a secondary distance indicator. Distances to early-type galaxies may be inferred from relations such as $D_n - \sigma$ and FP, which relate different observable quantities that depend on the distance of the galaxy (e.g., d_n, FP) to a redshift independent quantity such as the central velocity dispersion. For studies of the peculiar velocity field it is common practice to derive these relations for galaxies in clusters, presumed to be at the same distance. To improve the statistics data from different clusters are combined to derive a template relation (e.g., Giovanelli et al. 1997b, Bernardi et al. 1999b).

For the purpose of deriving $D_n - \sigma$ and FP template relations we have compiled the ENEARc sample

described above. It comprises 577 galaxies with d_n, 473 with FP parameters, and 586 with σ, yielding a sample of 569 and 431 cluster galaxies to derive a $D_n - \sigma$ and FP relations, respectively. Of these we have obtained new $R-$band photometric parameters for 315 galaxies, high-quality spectra for 235, and combined with other available data we have added 153 new distance measurements, which 93 had no prior measurements.

Until recently most studies of peculiar velocity using early-type galaxies relied on $D_n - \sigma$ distances, with the FP being used primarily for more detailed stellar population studies and of possible environment effects. While it is our intention to compute both distance relations and investigate possible effects on the results of the analysis of the peculiar velocity field, our preliminary analysis of the data is based on the $D_n - \sigma$ relation derived by Bernardi et al. (1999b), postponing to a future paper the derivation of the FP template relation (Alonso et al. 2000c). This choice was motivated by the larger number of measurements of d_n available, the fact that this quantity is less sensitive to seeing effects, and the parameterization used in fitting the light profiles, as required for determining the half-light radius r_e and the mean surface brightness $\bar{\mu}_e$ that enter in the FP relation. Moreover, recent studies have shown that the scatter about this relation is comparable to that obtained using the FP relation (e.g., Jørgensen, Franx & Kjærgaard 1996; D'Onofrio et al. 1997).

4.2. Pruning the sample

As described in section 2, The ENEARm sample is defined from a combination of catalogs, therefore, it is not surprising that some pruning of the sample is required both before and after the observations. In general, galaxies were inspected before the observations, especially after the availability of the DSS. At this point some galaxies were immediately removed because of one of the following reasons: stellar contamination; crowded fields preventing a good determination of the background; interacting galaxies; contamination/superposition by neighboring galaxies of comparable size and/or brightness; and morphological misclassifications, especially late-type spirals. We have also discarded galaxies during the analysis of CCD images whenever they revealed features not discernible in the DSS due to saturation in the inner parts of the images. A common cause is the presence of relatively bright stars superposed on the central parts of the galaxy image, making the reliable determination of photometric parameters impossible. A complete description of these cases will be presented in Alonso et al. (2000a). We have also removed ~ 100 galaxies from the sample after analyzing their spectra. These cases include galaxies with strong

emission-lines but very weak absorption features, galaxies with small velocity dispersions (depending on the spectral resolution used) and low surface brightness galaxies with low S/N spectra ($\lesssim$10 − 15) (see Wegner et al. 2000). In total, roughly 250 galaxies were discarded for these reasons reducing the ENEARm sample from 1847 to 1607. This culled sample is used below as a reference in estimating the completeness of the ENEAR survey.

Finally, when compiling the peculiar velocity catalog, galaxies with extremely large peculiar velocities were re-examined and those with old photometric or spectroscopic measurements or with some peculiarity in their images (prominent bars, shells, spiral arms, dust lane) that could either affect the derivation of the photometric parameters of interest or lead to a significant departure of the galaxy from the distance relation were removed ($\sim$ 200 galaxies) from the sample used for peculiar velocity analysis (Alonso et al. 2000d).

4.3. Grouping galaxies

In contrast to late-type galaxies, early-type objects tend to reside in virialized clumps and in regions of high density. Therefore, in order to use early-type galaxies to map the peculiar velocity field it is important to assign them to groups and clusters, in order to minimize the impact of virial motions on the analysis of the velocity field. One advantage of grouping galaxies is that the distances to grouped objects are more accurately determined, as the fractional distance errors are reduced by a factor of $\sqrt{N}$, where N is the number of early-type galaxies in the group.

Since our sample has been drawn from complete redshift surveys, membership assignment of galaxies to groups can be done in a systematic way, using objective friends-of-friends algorithms to search for galaxy groups in the original magnitude-limited catalogs. To this end we have used the catalogs of groups of Maia et al. (1989) for the SSRS and of Geller & Huchra (1983) for the CfA1. These groups were defined as associations of galaxies with a density contrast $\delta\rho/\rho > 20$. These catalogs have been used as they provide the largest sky coverage. In regions covered by CfA2 and SSRS2 we have replaced these groups by those recently compiled by Ramella et al. (1997) for the CfA2 and by Ramella et al. (1999) for the SSRS2. These surveys cover a slightly smaller area but extend to fainter magnitudes and consider groups with larger density contrast $\delta\rho/\rho > 80$ which, as demonstrated by numerical simulations, are less contaminated by spurious groups (members). Finally, groups have also been identified at low galactic latitudes using the ORS data kindly provided by B. Santiago and M. Davis. Using the position and parameters of these groups, early-type galaxies were assigned to a group if their projected separation relative to center of a group was

$\leq 1.5R_p$ and their redshift satisfied the condition $(cz_{\rm gal} - cz_{\rm gr}) \leq 1.5\sigma_{\rm gr}$. Here, R_p is the mean projected separation of the group (Ramella et al. 1989), $cz_{\rm gal}$ is the radial velocity of the early-type galaxy, $cz_{\rm gr}$ is the mean group velocity and $\sigma_{\rm gr}$ is the velocity dispersion of galaxies in the group. We adopted these criteria in an attempt to homogenize the assignment of galaxies to groups, given the differences in density contrast used in their original identifications, and to allow for the identification of systems which may have been missed near the edges of the catalogs.

Adopting the above criteria we find that 59% of the early-type galaxies in ENEARm are in groups. We point out that 15% of the galaxies are associated with groups in which the other members are late-type galaxies. Such systems represent about 10% of the total number of groups. In the latter case the peculiar velocity of the galaxy is computed using the galaxy's distance, while the redshift is that of the group. Groups containing two or more early-type galaxies are treated as single objects with the redshift being given by the mean redshift of the group, including all morphological types, and the logarithm of the distance as the error-weighted mean of the logarithm of the distance of the early-type galaxies in that group. Figure 8 shows the number of groups as a function of the number of early-type galaxies in the group. We note that in the case of clusters within $cz \leq 7000$ kms^{-1} used to determine the distance relations (see section 2.2) we have also used fainter galaxies in the calculation of their redshift and distance. As discussed above (see also Bernardi et al. 1999a), we arbitrarily define clusters to be systems with more than 10 members, of which at least 5 are early-type galaxies. This cluster sample is used by Bernardi et al. (1999b) and Alonso et al. (2000c) to define the template distance relation later used to estimate galaxy distances. Finally, we point out that the membership assignment criteria described above was adopted by Bernardi et al. (1998) to investigate the properties of early-type galaxies in different environments.

Figure 9 shows the projected distribution of the 1141 "objects" in the ENEARm sample. The upper panel shows the 748 galaxies not assigned to groups, while the lower panel shows 393 groups/clusters. As expected, the "isolated" galaxies are more uniformly distributed across the sky, while the group/cluster sample delineates more clearly the most prominent large-scale structures in the nearby universe.

4.4. Completeness

Since our parent sample has complete redshift information, completeness here refers to galaxies for which we have both velocity dispersion and d_n measurements and thus $D_n - \sigma$ distances. Figure 10 shows the completeness function of the ENEARm redshift-distance survey as a function of: (a) redshift,

(b) blue magnitude m_B, (c) galactic longitude, and (d) galactic latitude. The completeness is computed relative to the sub-sample of 1607 galaxies that remain after excising galaxies, from the original sample of 1847 galaxies, unsuitable for distance estimates, as discussed above. Examining the figure we find no strong dependence with the redshift, magnitude, or galactic longitude and latitude except near the southern galactic pole ($b \lesssim -70°$). In general, the sample completeness is a nearly constant $\gtrsim$80%. This demonstrates that our dataset, even though not complete is remarkably uniform both in depth and in sky coverage. This is in marked contrast to other catalogs assembled from different sources (e.g., Mark III) which show large sampling variations in different directions of the sky. We have not investigated the completeness of the sample as function of morphological types since analysis of our images shows that the morphological classification available from the original catalogs is unreliable and care should be exercised in defining sub-types of the early-type population for any detailed analysis of their properties. We note that the information presented here is useful for producing realistic mock samples for analysis of the peculiar velocity field.

To underscore the uniformity of the observed sample Figure 11 compares the projected distribution, in galactic coordinates, of all galaxies of the ENEARm sample that have measured distances (filled circles) with galaxies for which distances are still unavailable (open circles). Clearly, the sample with measured distances delineates well all major structures in the nearby universe. We also find that the distribution of missing galaxies does not reveal any particularly under-sampled region.

So far, we have shown all galaxies individually. However, as discussed earlier, early-type galaxies are found predominantly in clusters/groups. Therefore, Figure 12 shows the distribution of independent objects defined by the grouping procedure described in section 4.3 (and in more detailed in Bernardi et al. 1999a). Currently, we have distances for 1644 galaxies, 1359 in ENEARm. The remaining are galaxies in the ENEARc cluster sample but not in the ENEARm. We include these galaxies because they are actually used in the definition of the redshift, distance and error estimate for these clusters. Figure 12 shows that there are 811 independent objects of which 6 are clusters beyond 7000 kms^{-1} . As briefly mentioned in section 4.2 about 200 galaxies show, after closer inspection of cases with extreme values of the peculiar velocity, features in their spectra and/or in their images that can affect the measured parameters that enter the distance relation and as a precaution were removed from the sample. A detailed description and listing of these cases will be presented by Alonso et al. (2000d). At the present time the sample being used in our preliminary analysis (da Costa et al. 2000; Zaroubi et al. 2000) consists of 1430 galaxies grouped in 702 objects.

4.5. Comparison with other surveys

The ENEARm sample shown in Figure 11 is the largest and most homogeneous sample of nearby early-type galaxies currently available for cosmic flow studies. To highlight this, Figure 13 compares the projected distributions, in redshift slices, of the ENEARm and the 7S samples after galaxies are grouped. Besides the obvious differences in the total number of galaxies and objects, there is a striking difference in the structures probed by the two samples. In particular, in the most distant redshift shell, Perseus-Pisces is clearly visible in our catalog while is conspicuously absent in the 7S sample. This accounts for some of the surprises encountered in earlier (7S-based) reconstructions (Dekel et al. 1990).

It is also worth comparing our sample with catalogs built from recently completed TF surveys. Figure 14 compares the projected distribution of individual galaxies having measured peculiar velocities in ENEARm and the SFI TF-survey of spiral galaxies. From the figure one can see the complementarity of these samples. The ENEARm early-type galaxies delineate the structures more sharply while the spirals are clearly more uniformly distributed. For this reason, the combination of the two samples is highly desirable, and it is the subject of future work.

Finally, as a preview for future papers in this series we present in Figure 15 the homogeneous Malmquist bias corrected peculiar velocities of the ENEARm galaxies within ± 5000 kms^{-1} from the Supergalactic plane in the CMB rest frame. For comparison we show the map of the flowfield as probed by the 7S. The most remarkable features are the suggestion of a back-side infall in the direction of the Great Attractor region and the flow associated with the Perseus-Pisces complex nearly absent in the 7S sample. A detailed analysis of the velocity field will be presented in subsequent papers of this series.

5. Summary

We have presented an overview of the ongoing imaging/spectroscopic survey of nearby early-types being conducted in both hemispheres which allowed the construction of an extensive and homogeneous database consisting of redshifts, central velocity dispersion measurements, spectral line indices and photometric data for roughly 3400 early-type galaxies, with multiple measurements in the nearby Universe ($z \lesssim 0.05$). Since these galaxies are part of complete redshift surveys additional information is also available regarding the type of environment and measures of the local galaxy density, making the catalog useful for different applications.

We have also discussed in some detail how a magnitude and redshift-limited sample of galaxies with measured distances and redshifts suitable for studies of the local peculiar velocity field has been constructed. The resulting ENEARm sample together with the cluster galaxy sample ENEARc, constitute the basis of the work being carried out by our group to map the peculiar velocity field as probed by early-type galaxies. We hope that the comparison of the peculiar velocity fields derived from the ENEAR survey and similar TF-based surveys will provide a more definite answer about the true physical nature of the observed motions, thus supporting the assumption that the peculiar motions observed are in fact induced by the gravity field associated to fluctuations of the underlying mass density field.

Quantitative analysis of various aspects of the measured velocity field such as the calculation of the dipole, the mass power-spectrum, and determinations of β will be presented in subsequent papers of this series. In the future, we also hope to be able to combine the ENEAR and SFI samples to obtain improved maps of the underlying mass distribution. Finally, we also anticipate the use of our dataset for more detailed stellar population studies.

We point out that observations are still underway, with the aim of completing the ENEARm sample and to extend the number of clusters available for the construction of distance relations.

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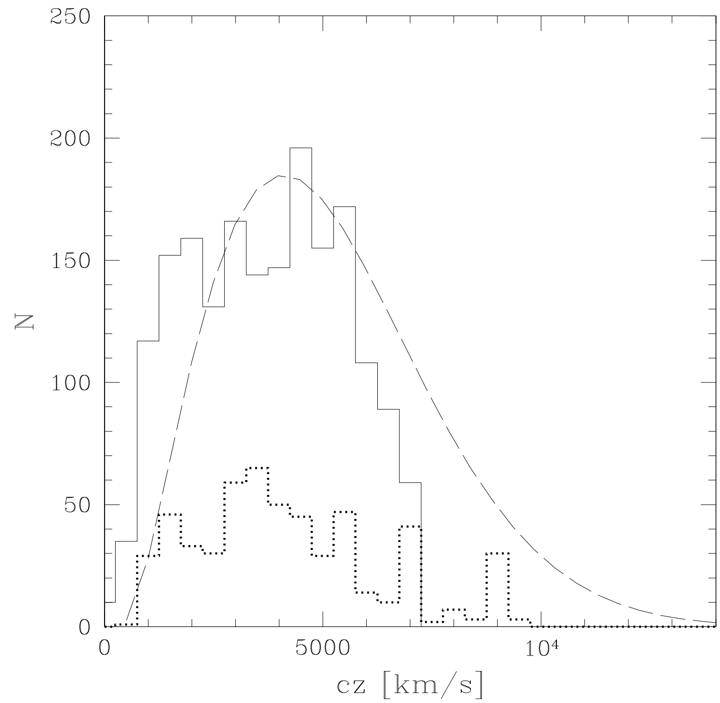

Fig. 1.— Redshift distribution of galaxies in the magnitude and redshift-limited ($cz \leq 7000$ kms^{-1}) ENEARm sample (solid histogram) compared to that of the 7S sample (dotted histogram). The dashed line is the redshift distribution predicted from a uniform distribution of early-type galaxies with a luminosity function given by that determined by Marzke et al. (1998) for early-type galaxies in the SSRS2

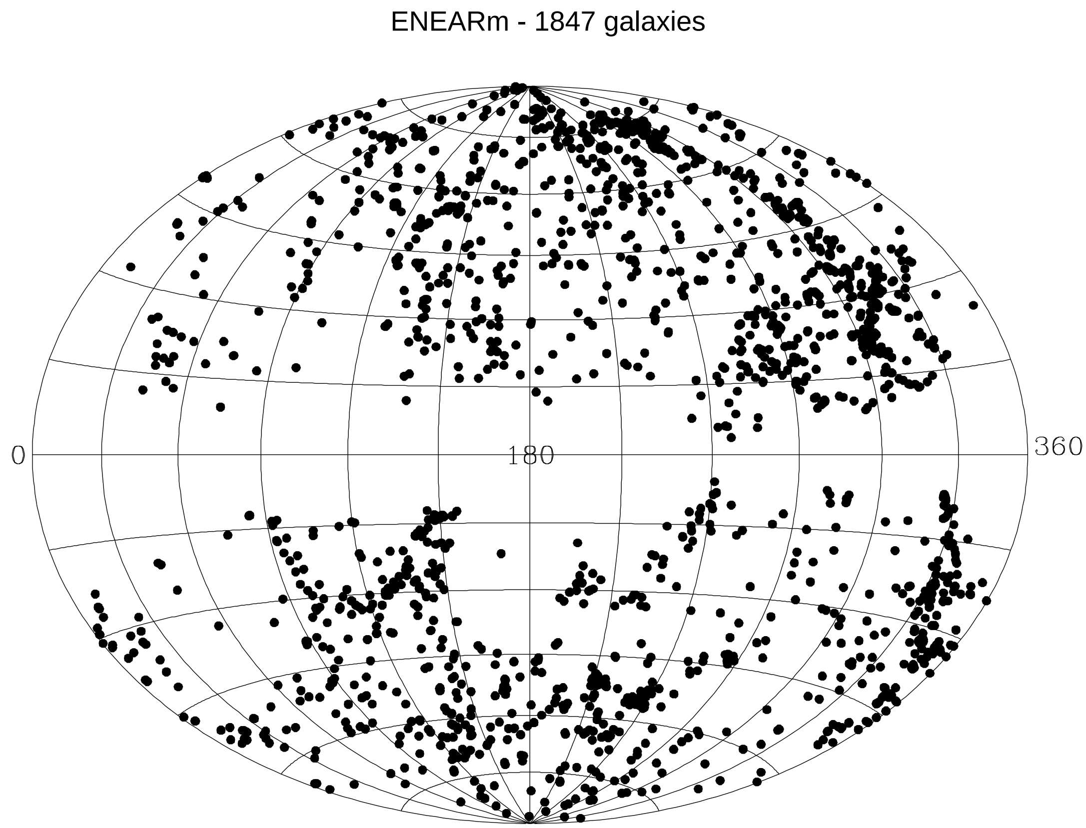

Fig. 2.— The projected distribution in galactic coordinates of the early-type galaxies in the magnitude and redshift-limited ENEARm sample as extracted from the parent catalog before pruning galaxies unsuitable for distance estimates (see text)

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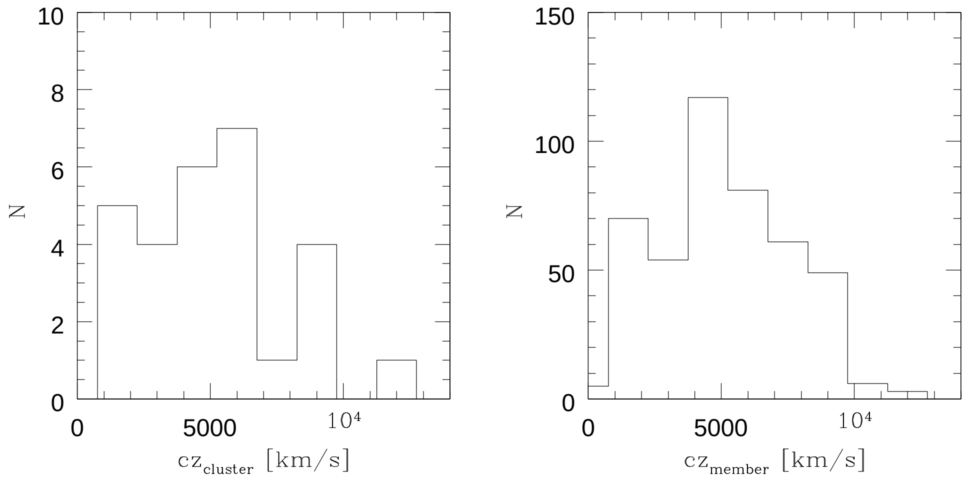

Fig. 3.— Redshift distribution of clusters (left panel) and cluster members (right panel) in the ENEARc sample.

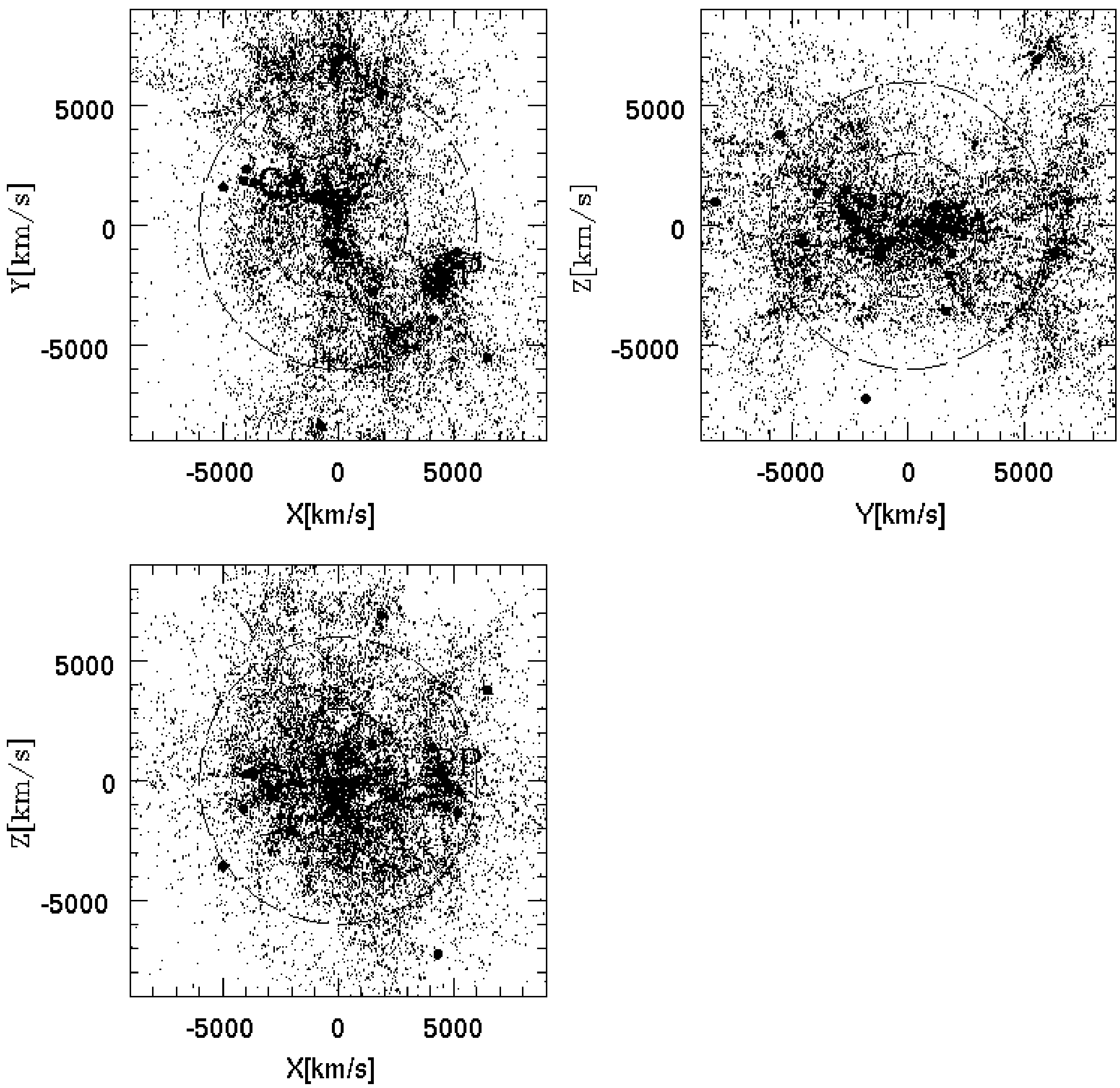

Fig. 4.— The spatial distribution of the 28 ENEARc clusters in Cartesian Supergalactic coordinates (X, Y, Z), expressed in kms^{-1} in the CMB reference frame. The two dominant concentrations of galaxies, the Great Attractor (GA) and the Perseus-Pisces (PP) superclusters, are indicated on the three panels. Small dots show the objects in the parent magnitude-limited redshift survey samples from which our catalog is drawn.

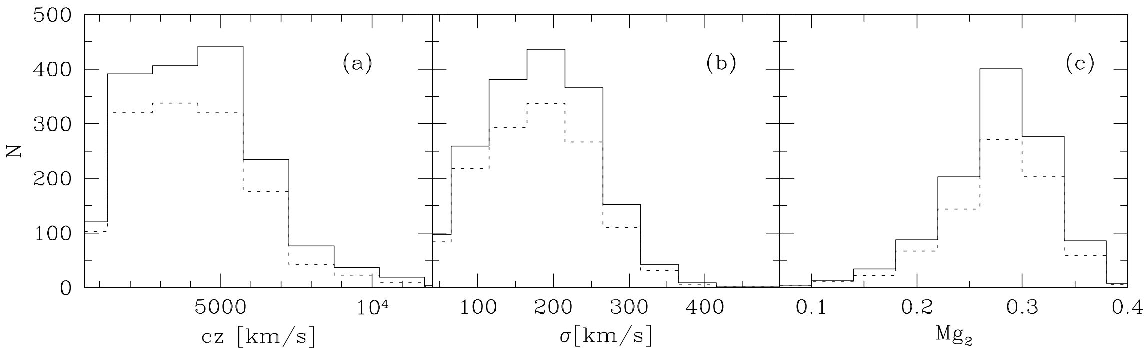

Fig. 5.— Distribution of redshift (panel a), central velocity dispersion (panel b), and Mg_2 line index (panel c) for galaxies observed by the ENEAR survey. Dotted histograms represent observations at high-resolution ($\lesssim$2.5Å). The plots show the total number of observations including multiple observations of the same object.

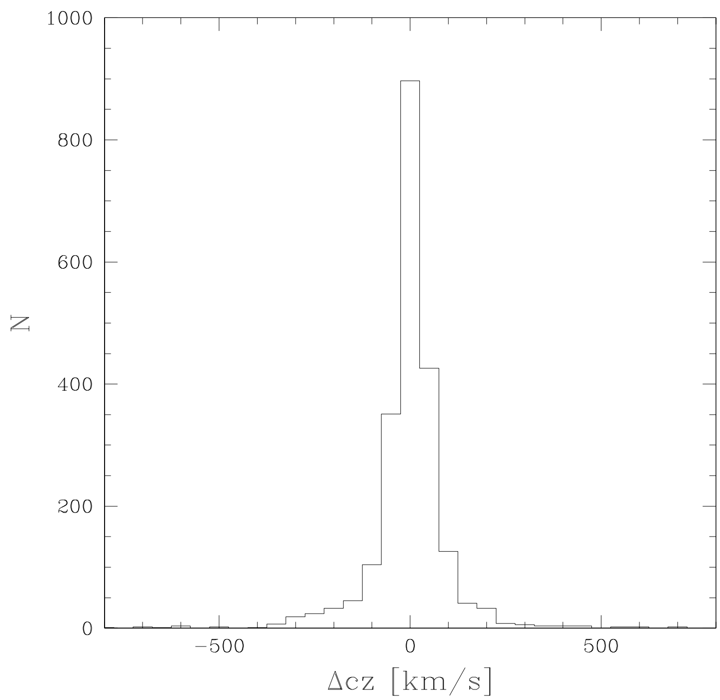

Fig. 6.— Distribution of the differences between our new redshifts and those previously available in the literature.

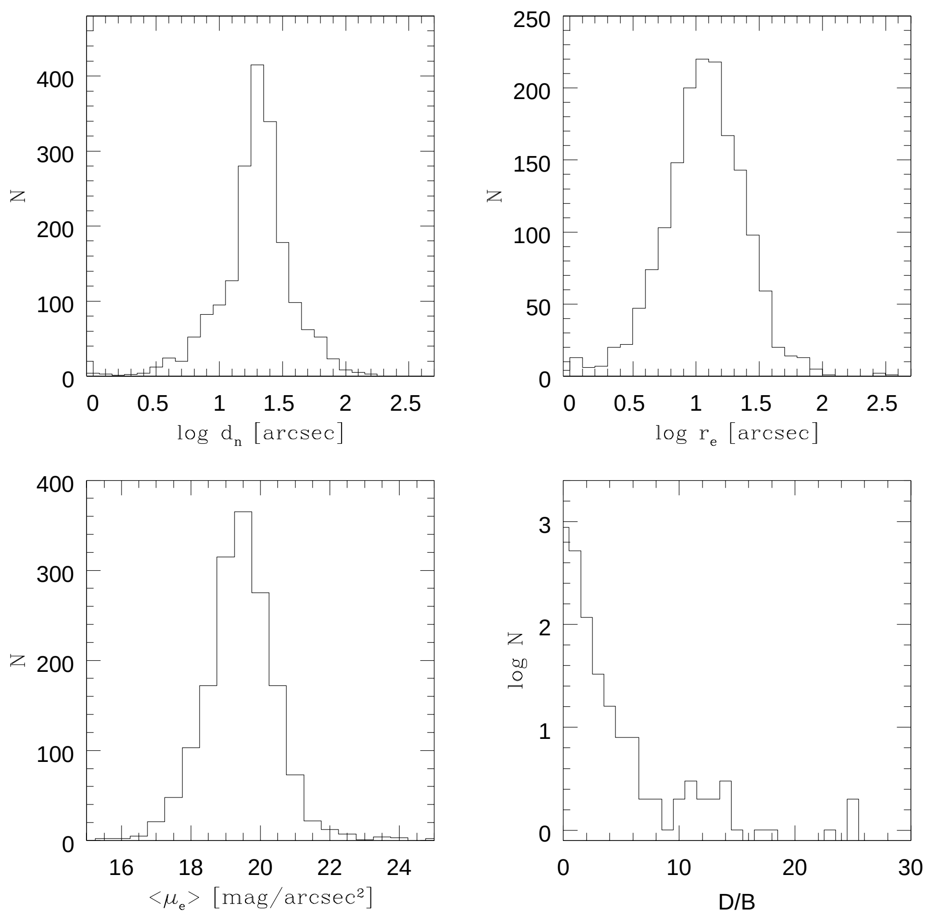

Fig. 7.— Distribution of observed photometric parameters: $\log d_n$, $\log r_e$ (d_n and r_e in arcsec), $\bar{\mu}_e$, and the D/B ratio.

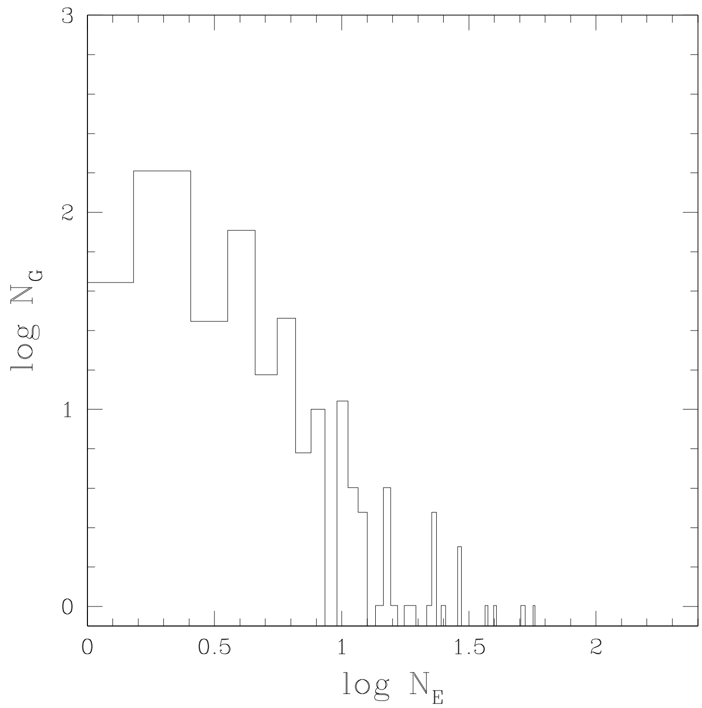

Fig. 8.— Multiplicity function of early-type galaxies showing the number of groups as a function of the number of early-type galaxies in the groups.

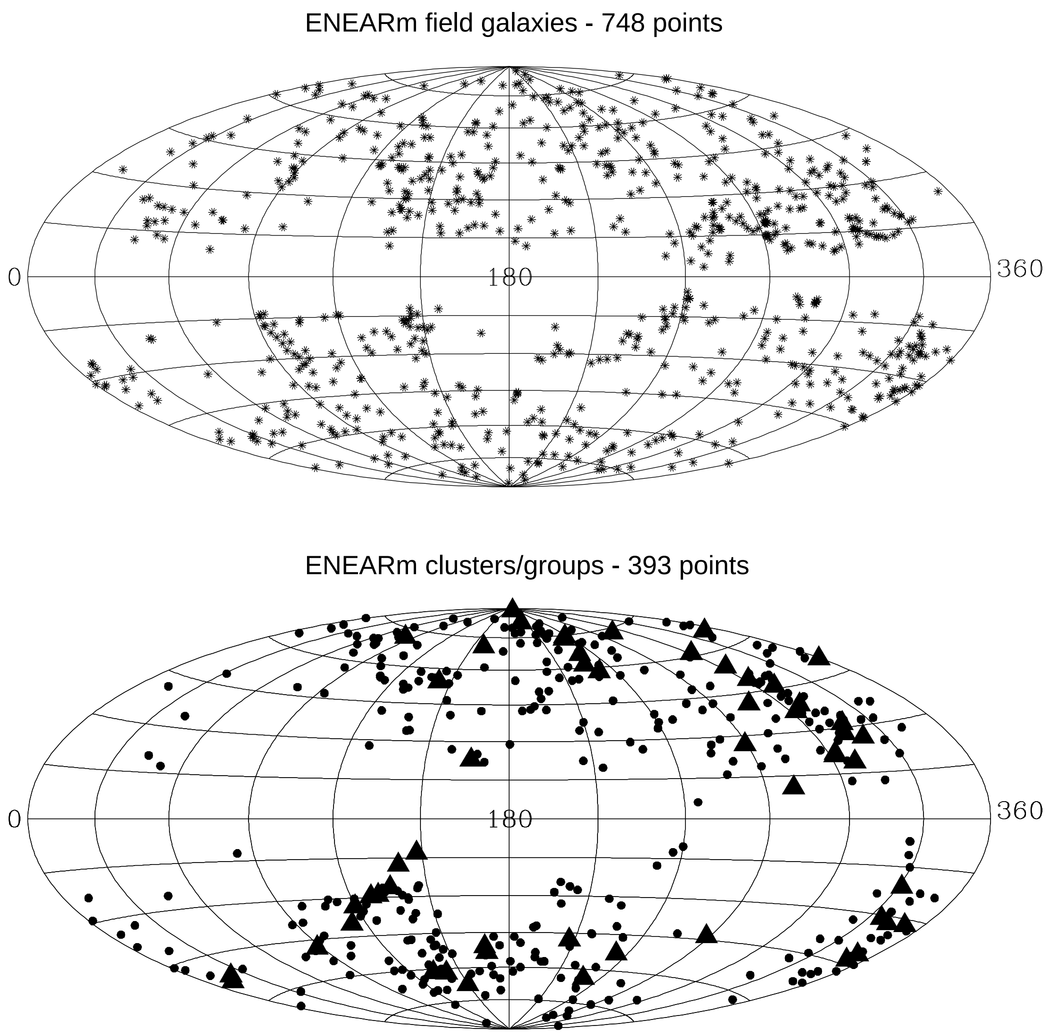

Fig. 9.— The projected sky distribution, in galactic coordinates, of the ENEARm objects. The upper panel shows individual galaxies considered as isolated by the membership criteria adopted. The lower panel shows the distribution of “objects” to which objects have been assigned, distinguishing groups (solid circles) and clusters (solid triangles) as defined in the text.

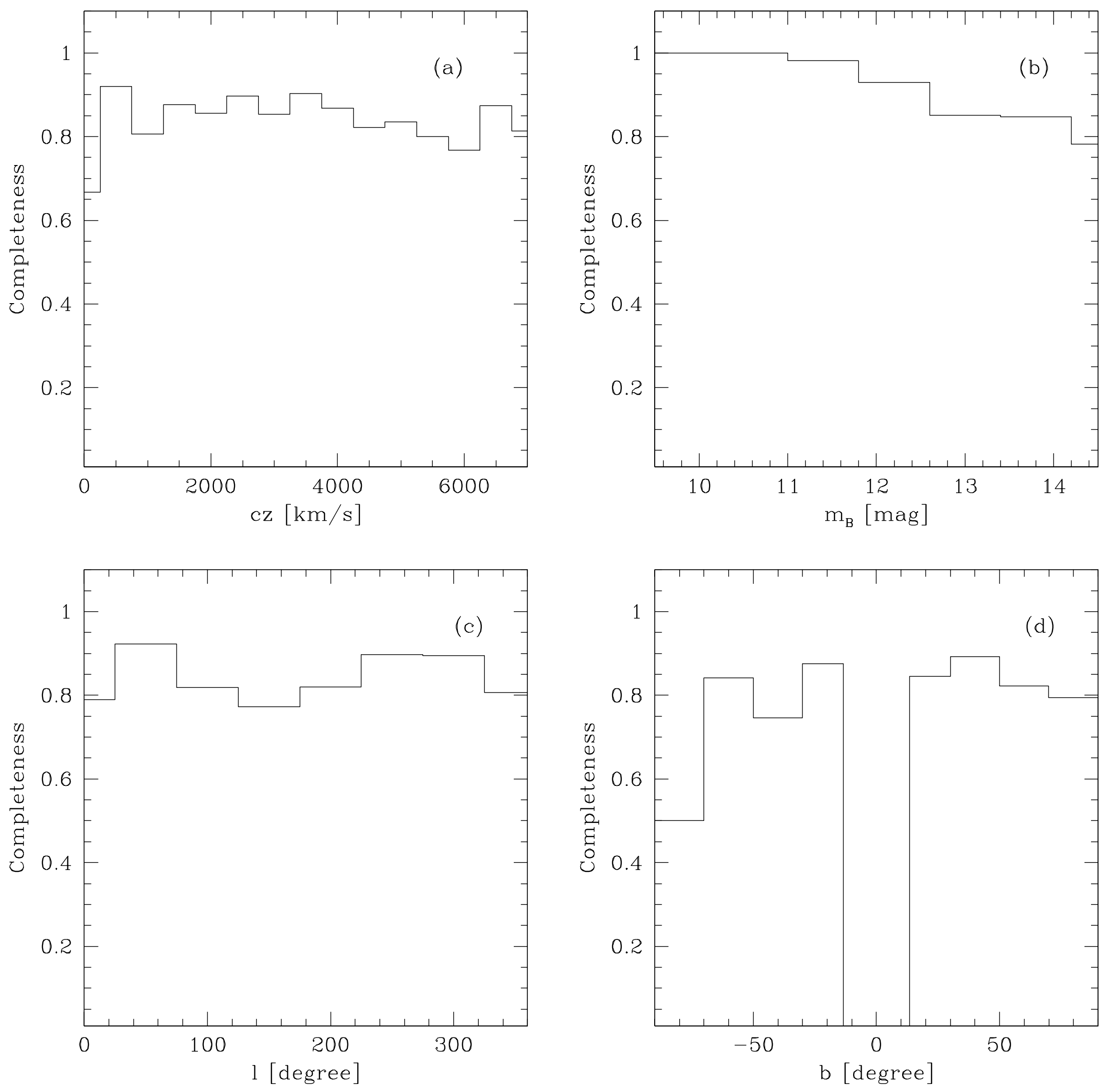

Fig. 10.— The completeness of the ENEARm sample as function of: redshift (panel a), magnitude, m_B (panel b); galactic longitude (panel c); and galactic latitude (panel d).

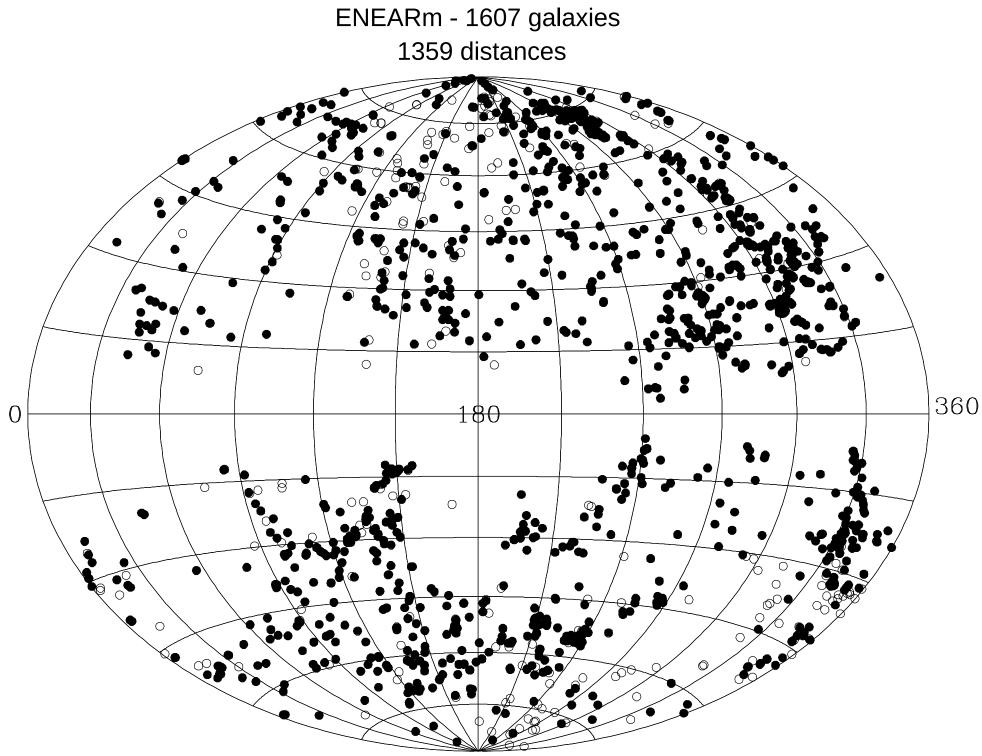

Fig. 11.— Projected sky distribution, in Galactic coordinates, of all ENEARm galaxies with (filled circles) and without (open circles) measured distances.

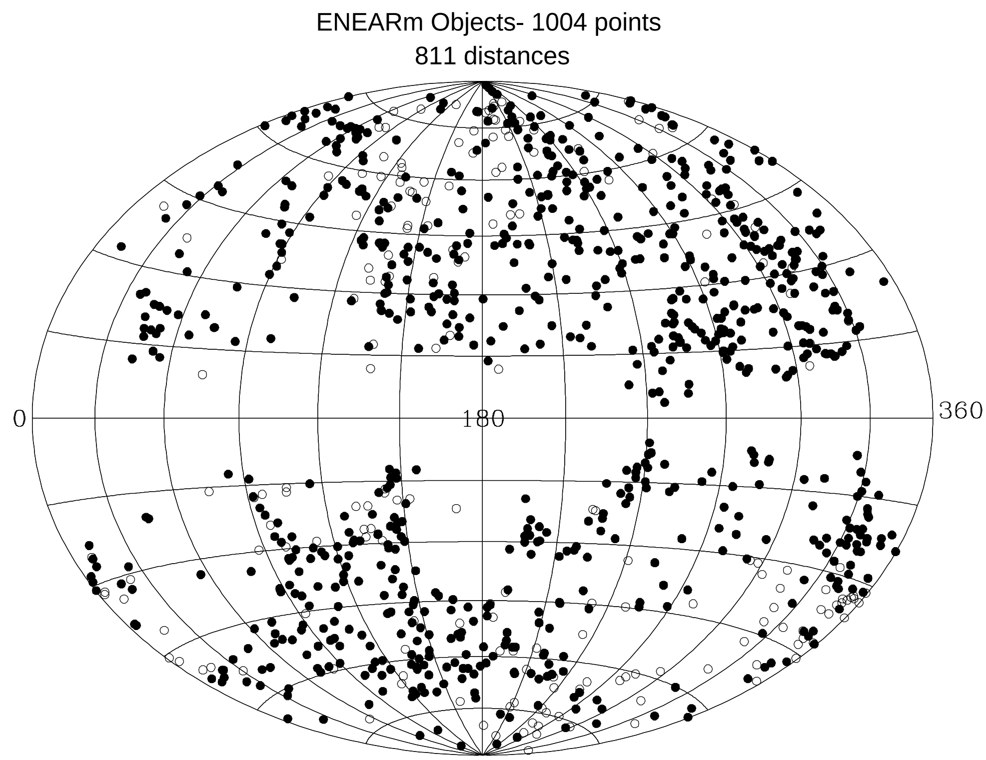

Fig. 12.— Projected sky distribution, in galactic coordinates, of ENEARm "objects" useful for peculiar velocity analyses showing objects with measured distances (full circles) and without (open circles).

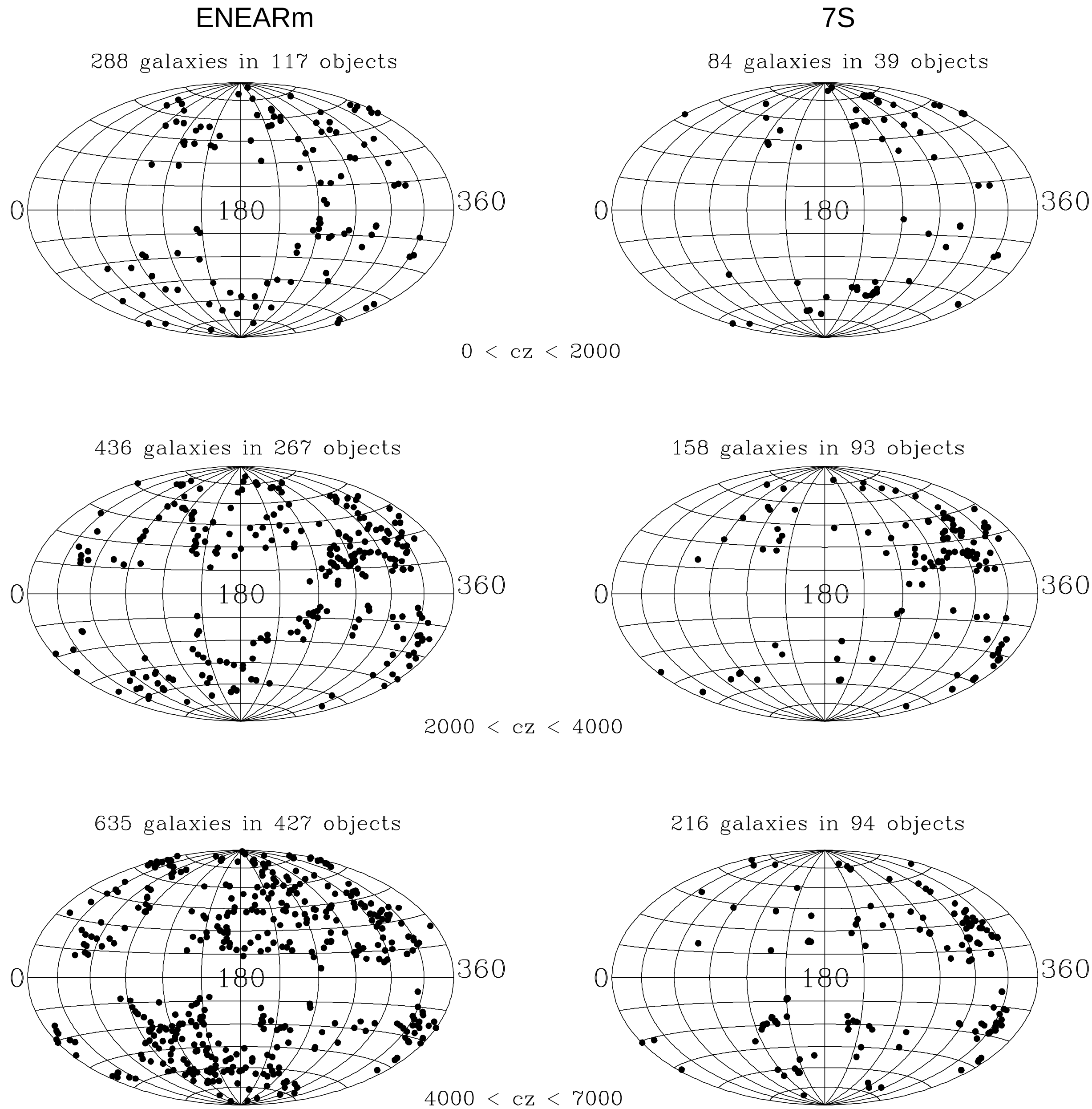

Fig. 13.— Comparison of the projected distribution, in galactic coordinates, of ENEARm and 7S objects in different redshift slices. The number of galaxies and the number of objects, after grouping, with measured distances are given for each redshift shell.

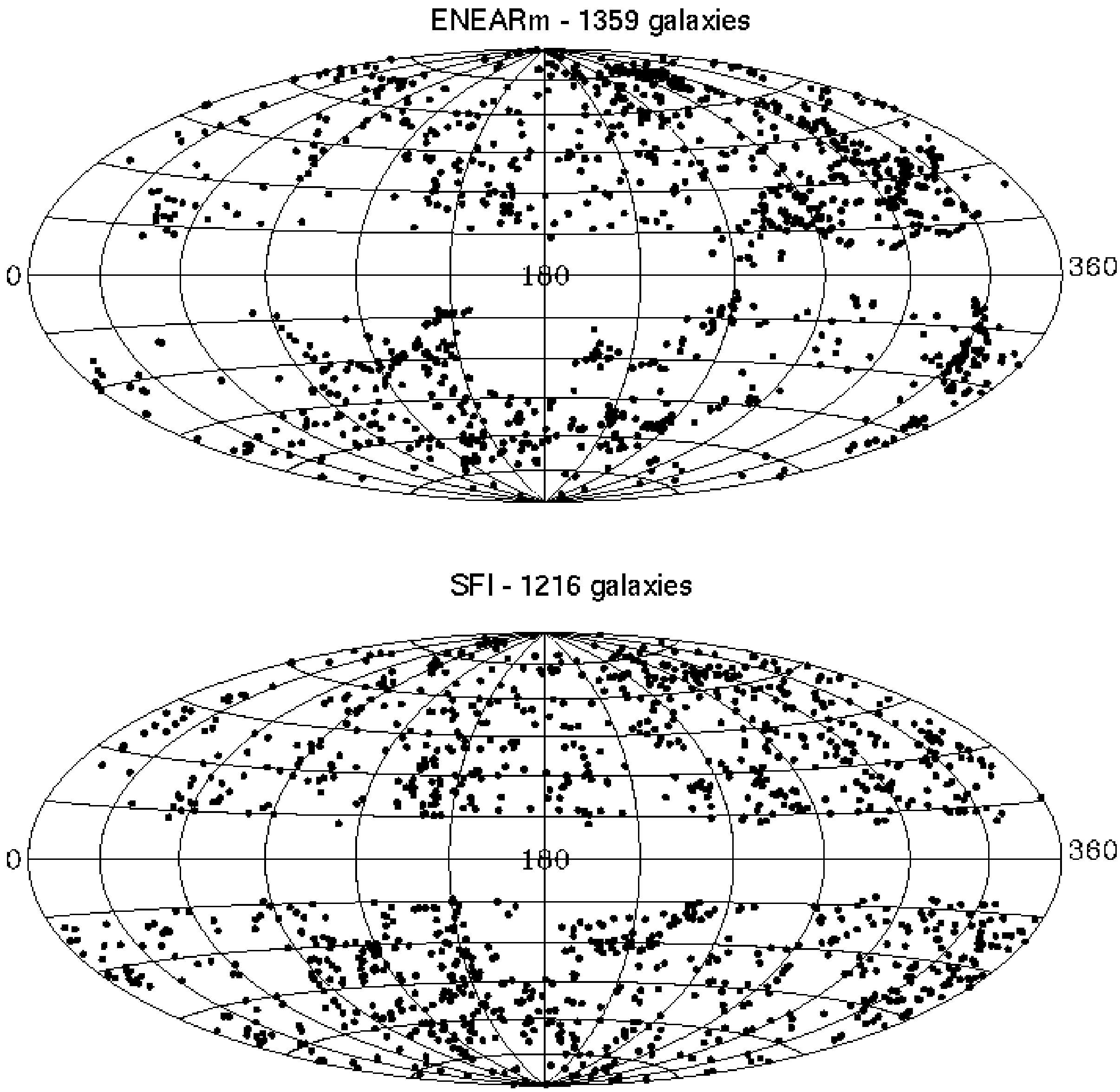

Fig. 14.— Comparison of the projected distribution of individual galaxies, in galactic coordinates, from the ENEARm sample (upper panel) and the SFI catalog of spiral galaxies (lower panel).

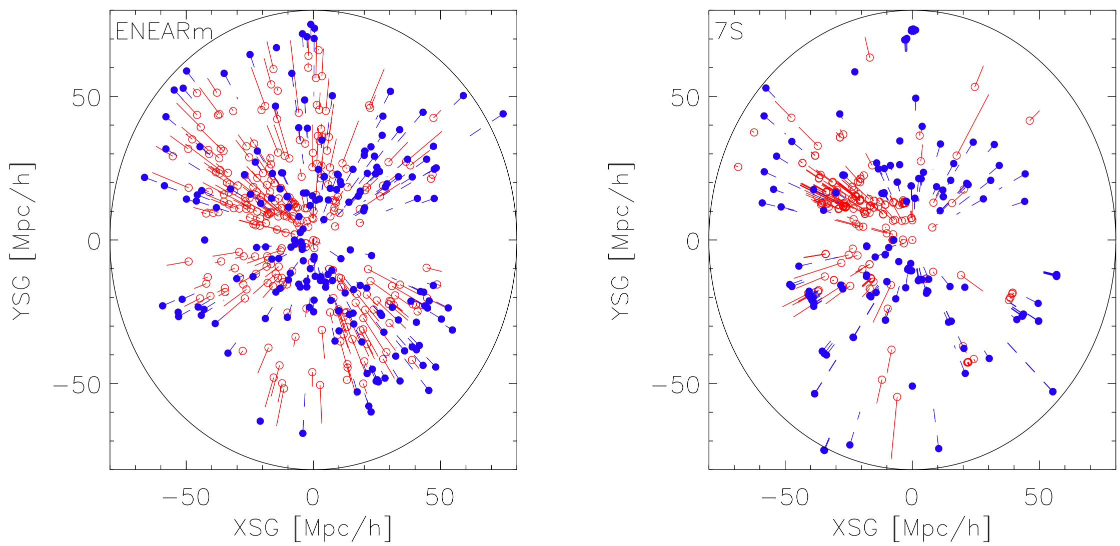

Fig. 15.— Map of the measured radial component of the peculiar velocity field in the CMB restframe along the Supergalactic Plane for the ENEARm (left panel) and 7S (right panel) objects within $5000 \mathrm{kms}^{-1}$ of this plane. Full symbols depict infalling galaxies and open symbols with dashed extensions outflowing galaxies.

Samples in the ENEAR catalog

Source	N_σ	$N_{\mathbf{Mg_2}}$	N_{D_n}	$N_{\mathbf{FP}}$
(1)	(2)	(3)	(4)	(5)
ENEAR	1210	1036	1398	1398
ENEAR+	792	792	–	—
TD (1981)	229	–	–	–
WMT (1985)	130	–	–	–
LC (1988)	114	–	78	–
7S (1989)	543	533	499	179
D (1991)	158	151	175	–
JFK (1992, 1995)	159	119	200	194
Lc (1997)	85	–	84	–
S (1997)	88	81	98	98

Note. — In the second column we give only the number of galaxies we have included in our catalog from the different sources. The original papers may contain more galaxies than listed here.

References. — TD: Tonry & Davis (1981); WMT: Whitemore, McElroy & Tonry (1985); LC: Lucey & Carter (1988); 7S: Faber et al. (1989); D: Dressler (1987), Dressler et al. (1991); JFK: Jørgensen, Franx & Kjaergaard (1992, 1995a, 1995b); Lc: Lucey et al. (1997); S: Smith et al. (1997).